CONTROLLER-PILOT DATA LINK RESULTS FROM NASA AND FAA DALLAS-FORT WORTH 2000 TEST AND DEMONSTRATION

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Abstract

The Controller's Communication and Situational Awareness Terminal (C-CAST) was recently tested and demonstrated at Dallas-Fort Worth International Airport. C-CAST is part of NASA's Runway Incursion Prevention System (RIPS) and the FAA's Runway Incursion Reduction Program (RIRP). The purpose of these programs is to assist pilots during low visibility, landing and surface operations and create a more reliable and efficient means of air traffic control. C-CAST has been developed to make the controller more aware of the surrounding traffic, generate text messages of controller commands for command verification and create a "heads up" environment for the controller.

The previously mentioned tasks were met by using a variety of resources that are integrated together to form C-CAST. Voice recognition is used to generate a text version of the Controller Pilot Data Link Communications (CPDLC) for an easy reference for the pilot and controller. A digital flight strip is generated to display these messages in an easy to read and convenient format. The CPDLC commands are encoded for transmission using a combination of ICAO and DO-219 formats. VDL Mode 2 radios were used to transmit the messages between the aircraft and controller ground station. C-CAST also receives traffic information from a Surveillance Server through a wireless TCP/IP connection and displays the aircraft on a zoomable map of the airport.

Testing and demonstrations at Dallas-Fort Worth were very successful for C-CAST and its developers. This paper will discuss in more detail the functions and architecture of C-CAST. It will also explain the connections to the rest of the RIPS

and RIRP equipment and its interactions with the equipment. Some results will be presented and a discussion of the future of the project will also be discussed.

Introduction

There are major issues being dealt with in today's air traffic control (ATC) community. With the consistent traffic increase in today's skies, the current system is being tested to its limits. A large amount of research is being conducted to help combat the problem of increasing complexity of today's ATC systems. One of the major areas of research is ATC automation. This will help take some of the burden from ATC controllers and pilots allowing them to concentrate solely on the issues that require human intervention. C-CAST is one possible tool for this operation.

The main purpose of C-CAST is to make the jobs of the ATC controllers and pilot's easier and more informative. By creating an easily operative environment, a lot of stress is relieved from its operators, allowing them to concentrate on more important tasks. Most accidents occur due to miscommunication between the pilot and the controller. The aim of the voice recognition system is to bypass these errors and ensure proper communication is established. Another major cause of accidents is due to weather and the pilot being unaware of his/her surroundings. The zoomable map and synthetic vision technology will help make these issues obsolete.

In August of 2000, NASA funded testing was conducted on the radio equipment for the C-CAST system at NASA-Langley Research Center in Hampton, Virginia and at Dallas-Fort Worth International Airport. These tests were to verify the proper equipment connections in a Boeing 757 test

aircraft, the function of these radios, the proper coding of controller commands and verification of radio coverage. In October of 2000, NASA funded flight tests were conducted at Dallas-Fort Worth International Airport, once again to test the radio coverage and interconnection of C-CAST with its other local systems (i.e RIPS and RIRP systems). Later, in October of 2000, NASA hosted VIP demonstrations of the entire runway incursion prevention system at Dallas-Fort Worth. These demonstrations were held to demonstrate the abilities and need for C-CAST and the other systems involved in the RIPS program.

In this paper a detailed discussion of the C-CAST system and its connections will be addressed along with results of the tests and demonstrations held in 2000.

ATC Automation

Among the many issues facing the air travel community is the lack of a truly efficient ATC system. Currently the system works quite well. However, it is being tested to its limits and the problem is only going to get worse. There are three issues that will be dealt with in this paper. These issues can be remedied by the use of an effective automated ATC system. These issues are the major burdens placed on the operators of the system, the need for a more efficient ATC system and the continual growth in aeronautical radio frequency congestion.

Controller/Pilot Burdens

Due to the large number of planes in the sky, controllers are busier than ever. Many controllers find themselves talking full time in order to handle the loads presented to them. In many cases, they are repeating the same information time and time again. The most common ATC message is to contact some other ATC facility on a particular frequency [1]. This type of repetition can take up a lot of time, making the system inefficient from a time standpoint. C-CAST's solution to this problem is the use of the manual interface to create and send the message with only the touch of a couple manual buttons. All the controller must do is select the aircraft from the map, hit the "Communication" button, select "Contact", select the desired facility

from a list of three choices, select the desired frequency also from a selection of preprogrammed choices, verify the message is correct and simply send the message. This is considerably faster than having to spell out the entire message verbally and reduces the probability of a miscommunication.

In order to reduce the complexity even further, a canned route can be developed for common tasks. This would reduce the number of buttons to only 2 or 3 and would send a full message displayed to the pilot. A later development could be the ability to digitally synthesize a voice that could speak the manually sent message along with the displayed message.

By implementing this type of system, the controller would be able to handle more aircraft in a fraction of time with less effort than before. They would not have to speak messages hundreds of times a day, reducing the effect of fatigue from constant repetition. This would make the controller more effective and possibly more alert.

ATC Efficiency

Today's skies are so congested that the sky is hardly large enough to handle the traffic. One possible remedy from the development of a more efficient data link is, once again, the ability to create and send a message in a faster amount of time.

According to an article on Controller/Pilot Data Link [1], the ability to speed-up communication can allow a faster aircraft turnover rate. With the current voice communication system, a horizontal en route spacing is 40 to 50 miles and could be reduced to only 10 to 20 miles under a more efficient communication system. Because of a faster message creation and receipt of confirmation, the spacing could be reduced thereby making the system more efficient.

This faster communication does not include the benefits provided by the other entities of the C-CAST system. C-CAST not only provides the controller with a faster means of communication, but it also has an easy to read visual interface and provides safety benefits as well.
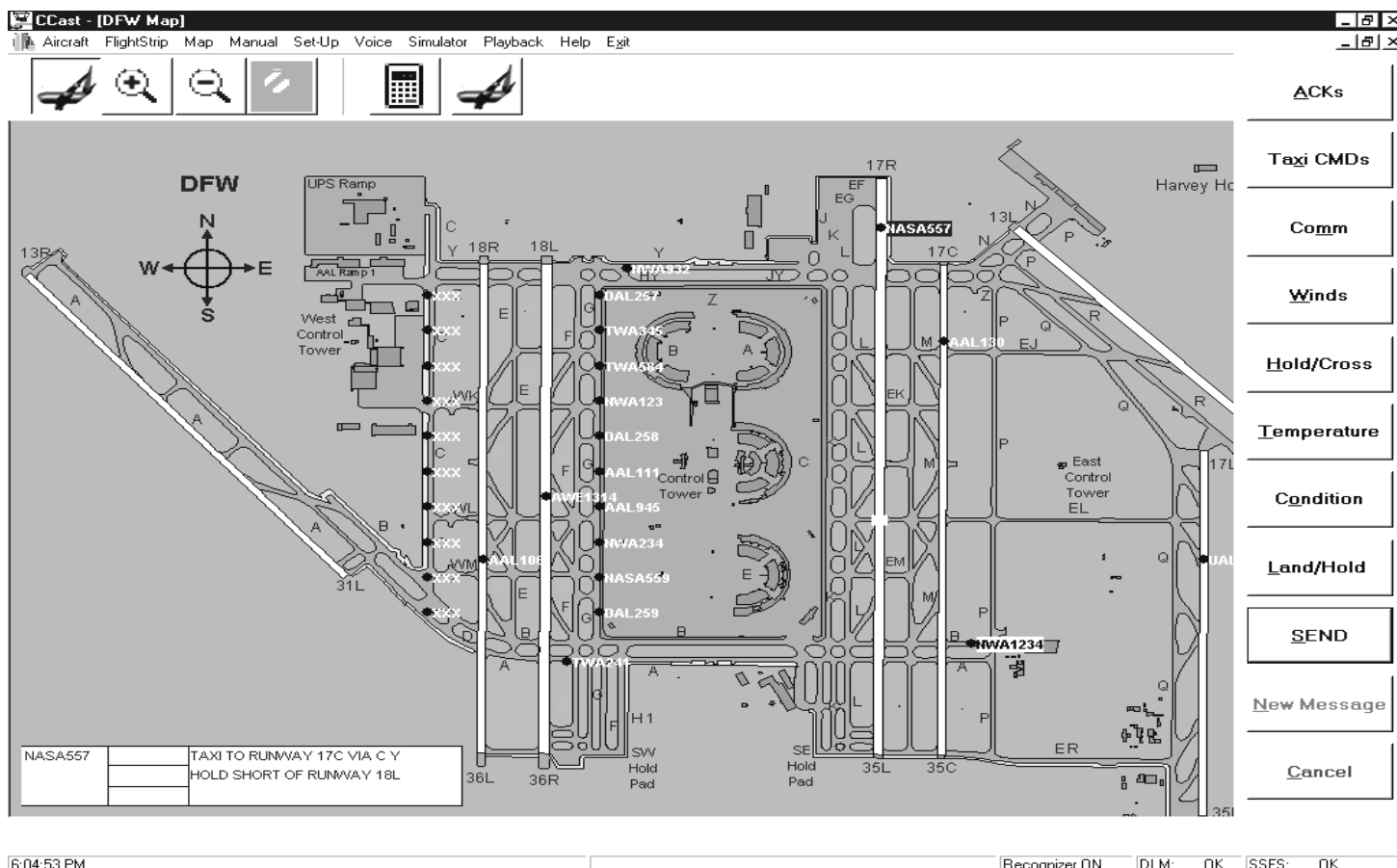
Figure 1 C-CAST Terminal – Map, Flight Strip and Manual Root Menu

Radio Frequency Congestion

As described in [1], ATC data-link can also have its effect on the current frequency congestion problem. Data-link communications technology is being pushed as a partial remedy for radio frequency congestion. Routine instructions and acknowledgements communicated via data-link take a fraction of the time required by current voice message systems. This can range from seconds for a data-link to even minutes in some voice environments.

Frequency time can be saved in two ways using a data-link. First, the digital messages are encoded so that relatively large messages are transmitted using only a few bits of data. Second, all spoken communication that is long-winded or cryptic, heavily accented, stepped upon, repetitious and often ambiguous or misunderstood are removed.

Once again repetitive messages can be accomplished using canned routes that take a fraction of the time a spoken message could be transmitted. This also can reduce errors and misunderstandings. The ability to transmit a long message with only a few bits can have a great effect on speed and frequency congestion.

The C-CAST System

C-CAST is comprised of and interacts with many systems. The software was developed for a Windows NT 4 platform using Borland C++ Builder 4. It uses a voice recognition software package developed by Lernout and Hauspie and VDL Mode-2 radios developed by Rockwell Collins.

C-CAST receives data from a Surveillance Server developed by VOLPE to obtain its traffic information. An Airborne Data Link Manager (ADLM) was developed by Sanjeev Gunawardena of the Ohio University team to interface with the

VDL Mode-2 radios and route the messages to their proper destinations. There is a Data Link Manager (DLM) on the ground, which connects all the ground systems, and routes all the ground data. Trios developed this system. All ground systems are connected to a Network Time Protocol (NTP), which time stamps all data transfers for synchronization and error detection purposes. It should be noted that C-CAST connects to a separate ground DLM than the DLM developed by Trios. This is due to the lack of information needed by other systems from C-CAST. C-CAST's DLM is a modified version of the ADLM developed at Ohio University.

All these systems combine to form the NASA and FAA Runway Incursion Prevention system. C-CAST is used on the ground, by a controller, to see the traffic on the runways and in final approach and allows them to send commands to any aircraft that has established a communication link. They are also able to see any traffic that has not established a communication link, but is detected by the local radar systems.

A controller can send a message to the aircraft via the voice recognition system or via an easy to use manual interface. Manual entries can be entered using a touch screen monitor or a mouse if preferred.

After the message is sent to the aircraft, it is then translated and displayed for the pilot. This serves as a visual backup in case of a misheard or misunderstood command. The message is translated by software developed by NASA Langley Research Center. A snapshot of C-CAST can be seen in Figure 1.

Manual Interface

The manual interface of C-CAST allows the user to send any possible message to the aircraft through a series of menus. There is a strip of buttons on the right of the screen. These buttons are the top-level menus for all the air traffic messages needed by the controller. A user must first select an active aircraft by highlighting its call sign and is then allowed to build a message.

Each top-level button has a series of sub-buttons that make up the entire message. Depending on the message, there may be several data entries needed in order to build the entire command.

Once a message is created, it is displayed in the center of the status bar in blue text. At this stage the message can either be sent or cleared for another entry.

While the messages are built manually, they are put through a message encoding process. This prepares the message for transmission to the aircraft. This is done using a combination of ICAO and DO-219 formats. The message is placed into an array, which is constructed throughout the entire message building process. The encoded messages are discussed in more detail later in the paper.

Voice Recognition System

The voice recognition system that is used by the C-CAST software is the ASR1602 system developed by Lernout and Hauspie. Students at St. Cloud State University in Minnesota integrated the voice system into C-CAST. This is a voice system that is user independent, meaning any person can use the system without any form of training unlike many older systems. A "grammar file" was developed, as a sort of dictionary, for the voice system. This file is used by the voice system as a reference for terminology and command structure.

When a command is spoken, the controller is given the opportunity to review the message before it is sent to the aircraft in order to verify the correct message has been spoken properly and accurately understood by the voice software. The text message is displayed in a "pop-up" window and the user can send or cancel the message. If the message is cancelled, the user is able to create a new message. If the user decides to send the message, it is then translated into a binary message format and sent to the radios for transmission. Even if a text message is not sent to the aircraft, the actual analog message is still heard by the pilot.

Once a command has been verified, it is sent to an encoding routine much like the messages that are obtained manually. This routine encodes the message into a binary format for radio transmission. A discussion of the encoding format will be included later in the paper.

After the message is encoded it is then sent to the ground DLM and routed to the radios for transmission. Once received by the aircraft, the message is decoded and displayed as a back up for the pilot. A more detailed description of the voice system can be found in [4].

Zoomable Map

The map feature in C-CAST allows the user to see all the aircraft that are detected by the local radar. The user can see the aircraft that have established communication and those that have not. If a comm. (communication) link is established, the call sign is displayed by the aircraft on the map. If a comm. link is not established, x's are displayed in place of the call sign. This can be seen in Figure 1.

The traffic data is supplied to C-CAST from the Surveillance Server and is updated twice a second. Also supplied to C-CAST are traffic warnings such as hold short commands. This shows up as a red line across a runway intersection.

A full map view of the entire airport is available as well as zoomed views of anywhere on the map. A simple press of a button can restore the map to its original state.

Another valuable asset supplied with C-CAST is the presence of hold bars when a hold short command is issued. Red or yellow lines appear at the intersections of runways and taxiways that indicated vehicles are not supposed to cross due to other aircraft approaching the intersection in question. Both the controller and pilot are able to see these lines on their displays. This will help reduce the frequency of runway incursions, making the runways safer and more efficient.

Binary Message Format

After a message is either spoken or entered manually into C-CAST and is accepted by the controller as the correct message, it is then translated into DO-219 and ICAO formats.

These are standardized formats for ATC Two-Way Data-Link Communications. Each command has their own DO-219 code number also called its "Element ID". This message is then imbedded into a message packet used by the DLM to transmit the message.

Table 1 shows the Element ID's for all the uplink messages. The identification number is the first data entered into the message after the preceding header. After the identification number, the rest of the message is dependent on the information necessary to complete the respective message. This follows the ATN-SARPS format as obtained from the 1999 2nd edition [3].

As mentioned above, the message is then embedded into a final message that is sent by the DLM to the radios for transmission [2]. This final message has a 20 bit preceding group that consists of a message type (Uplink or Downlink), message length, destination address, source address, a control bit (used by the radios), message number and the Aircraft Identification number (i.e. Call sign). Next comes the CPDLC Message followed by a checksum for error detection.

All data is translated into a binary representation of the ASCII values of all entered data.

Table 1 DO-219 Message Designations [5]

| Value	Meaning
0	UNABLE
1	STANDBY
2	REQUEST DEFERRED
3	ROGER
117	CONTACT [icaounitname] [frequency]
120	MONITOR [icaounitname] [frequency]
153	ALTIMETER [altimeter]
169	[freetext]
240	HOLD SHORT OF [position]
241	TAXI RUNWAY [runway] VIA [taxiroute]
242	TAXI RAMP [ramp] VIA [taxiroute]
243	CROSS [position] [without delay]
244	CONTINUE TAXI
245	UNAVAILABLE TAXIWAYS [taxiways]
246	RUNWAY [runway] TAXI INTO POSITION AND HOLD
247	RUNWAY [runway] CLEARED FOR TAKEOFF
248	WIND [direction] AT [speed]
249	RUNWAY CONDITION [condition]
250	LAND AND HOLD SHORT OF [runway]
251	TAXI TO GATE [gatenumber] VIA [taxiroute]
252	TEMPERATURE [temperaturec]
253	RUNWAY [runway] CLEARED TO LAND
254	TAXI TO SPOT [spotnumber] VIA [taxiroute]
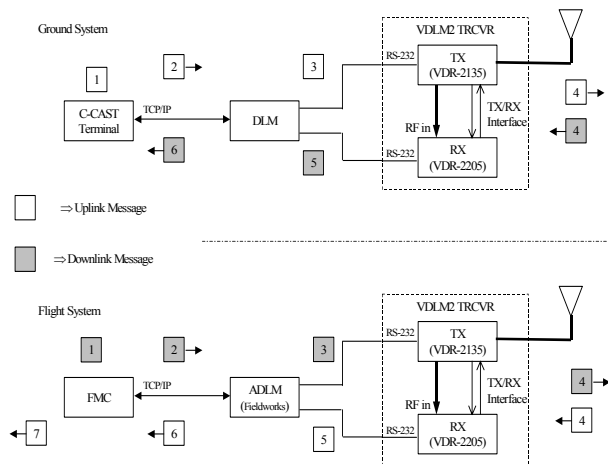
Figure 2 Langley, August Test Configuration [2]

Testing Configurations

C-CAST has undergone several testing procedures in the past year. The first of a series of tests occurred at NASA-Langley Research Center in Virginia in August of 2000. These tests were conducted to ensure proper installation of equipment on the test aircraft, radio communication verification and encoding and decoding of manual text messages. A week later, the aircraft radios were installed in a test van to simulate an aircraft taxiing on the runways. This test was conducted at Dallas-Fort Worth Airport and included radio coverage, system integration and error detection.

A few months later, in October 2000, flight tests were conducted at Dallas-Fort Worth Airport. These tests were conducted to determine the communication limits of the radios and system integration. Later in the month, public demonstrations were conducted for NASA, FAA and other industry professionals. The results and configurations are described in the following sections.

Langley August Tests

The testing configuration of these tests included a Boeing 757 test aircraft with the airborne equipment installed on the aircraft. The plane was in a large hangar and the ground equipment was located inside an office just a few yards from the aircraft. The airborne and ground configurations were as indicated in Figure 2.

These tests were primarily undergone in order to ensure proper communication between the ground and air stations. At first, the radios were unable to communicate and it was later determined that the DLM must be used on an NT platform due to some specific API calls that are not defined in Windows 98. After this problem was determined and fixed, communication between the radios went smoothly. A test of the encoding and decoding process was initiated. Sending all possible messages using the manual interface did this. A few bugs were found and the differences were worked out before the next round of testing.

Overall the tests were very successful. Lessons were learned about system debugging and integration. This round of tests also saved a considerable amount of money by verifying the message encoding process. It was more economical to work the problems out during the ground tests rather than during the much more expensive flight tests held in October 2000.

Dallas August Tests

The testing configurations of these tests were a little more complicated than those held in Virginia. These tests were primarily meant to test the radio coverage abilities of the VDL Mode-2 radios. They also served the purpose of making sure that all systems were in place and communicating with each other properly. C-CAST was connected to the Network Time Protocol, the Surveillance Server and Ohio University's DLM. The Surveillance Server was connected to Trios' Data Link Manager. This set-up can be seen in Figure 4.

During the day, all systems were installed and tested for proper set-up. The actual tests were reserved for late at night when the runways were clear of heavy traffic. There were two vans involved in the tests. One van carried the Trios equipment while the other held the airborne radio and ADLM for the Ohio University team.

The test vehicles were driven along the runways at high speeds (up to 80 mph) over the entire airport. The ground stations were located in a trailer by the East tower. A view of the radio coverage obtained is located in Figure 3. It can be seen from the figure that the strongest coverage was near the East tower, all the while still receiving
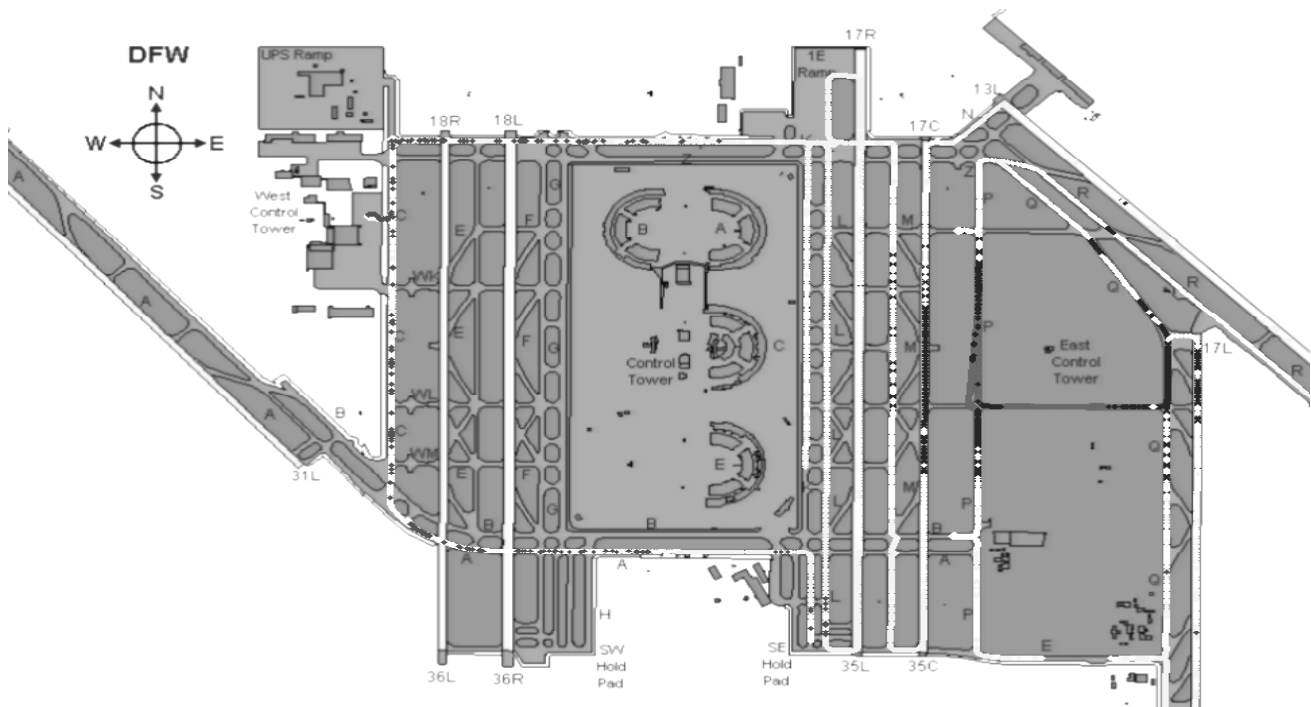
Figure 3: Radio Coverage DFW, August Tests [3]

good coverage everywhere on the airport surface. Due to the lack of color in Figure 3, it is difficult to see the coverage on the west side and in the center of the airport. However, adequate coverage was obtained over the entire airport surface. All connections for the RIPS system were tested and everything went according to plan for the Ohio University team.

Dallas October Tests

The October tests in Dallas were the actual flight tests and were meant to test the C-CAST system to its limits. The airborne equipment was installed in the Boeing 757 aircraft and the aircraft was flown for data collection. This consisted of 5 nights of data collection and 5 nights of checkout. This tested the abilities of the VDL Mode-2 radios to the max. The radios proved to be adequate for the needs of the C-CAST system, allowing communication to be established well before the aircraft reached approach distance. All communication went well and messages were transmitted and decoded successfully.

Dallas October VIP Demonstrations

The objective of the October demonstrations was to prove the capabilities and necessity for the RIPS system. It is at these demonstrations that the voice recognition capabilities of the C-CAST system were tested. Some errors needed to be worked out, but in the end the system performed with a nearly perfect performance.

All messages were correctly transmitted and decoded by the airborne system. The radios performed well and the overall tests were a success.

Future Work For C-CAST

Due to the demanding schedule of the project, it was very difficult to complete any in depth analysis of the performance of C-CAST and the other supporting systems. With out proper analysis of the program's performance, it is difficult to say what needs to be fixed or changed and where the system's place is in today's ATC community.

Future work on the project would mainly be analysis of the systems performance. Testing would have to be conducted to determine the accuracy of the voice system, efficiency of the
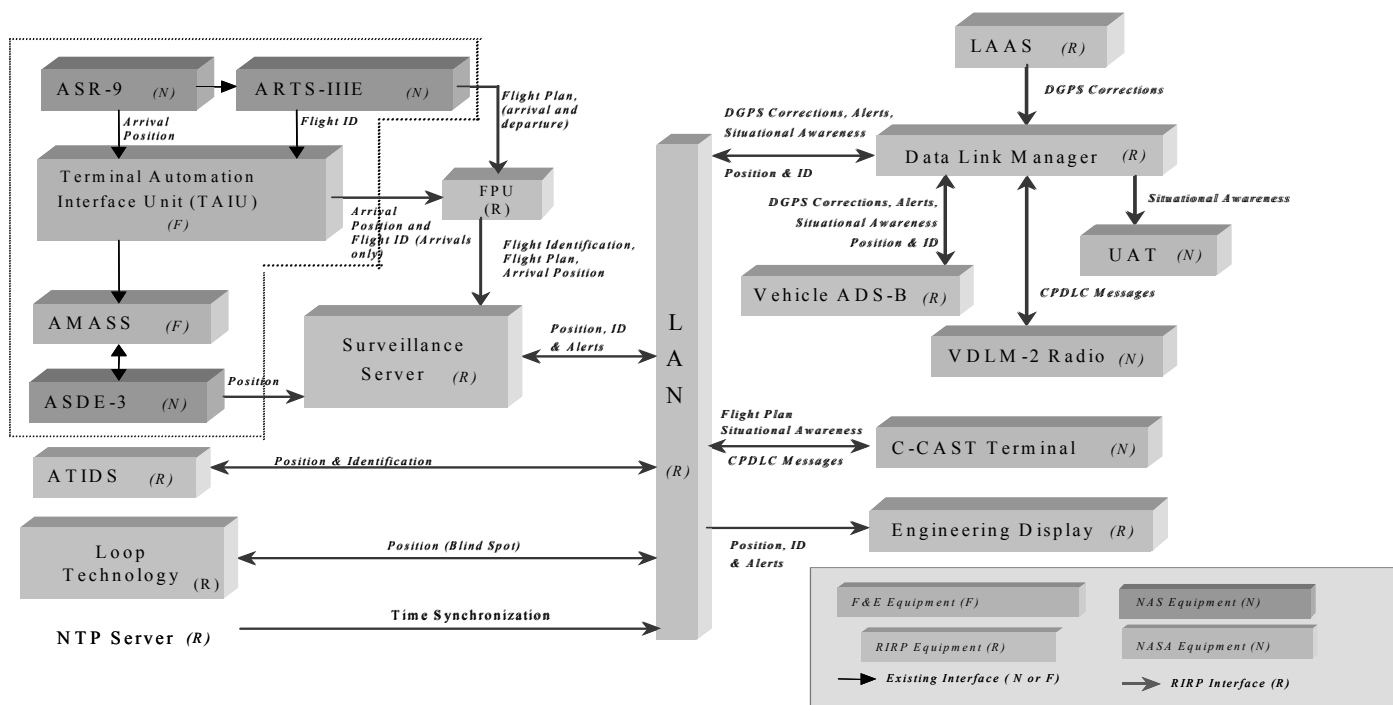
Figure 4 Ground RIPS Architecture – October, Dallas Tests and Demonstration [6]

written program and the dependability of all equipment and connections of those entities.

Also, a study on how easy the system is for pilots and controllers would have to be conducted. This would help decide what might need to be changed, removed or added. This would assure the system is put in its proper place in the ATC community.

A cost study would have to be done in order to determine the cost to implement the system. As with any change to the airline industry, cost is always an aspect that must be taken into consideration.

The Future of Controller/Pilot Communications

There is a lot of potential for future work in the area of Controller/Pilot communications technology. Some of which are being developed today. Among these developments is the use of a "Heads-up" virtual display for pilots and controllers. This allows the users to see messages or even routes mapped out for them, superimposed on their current view, there-by creating a truly "heads-up" environment for the user.

Another future development could be the mapping of the spoken command on a digital map for the controller so that the route can be verified before transmission [1]. This might be a little easier to review rather than the spoken message.

Some day a user might be able to simply draw the route on a digital map and then hit a button to encode the message into text, synthesized voice and even a copy of the digital route displayed on a map [1]. This would drastically shorten the time it takes to encode and send a message and might be less prone to errors since a visual reference would be provided.

Conclusions

The tests that were conducted from August to October of 2000 were very successful for the RIPS and RIRP participators and supporters. The system proved to be reliable under the testing conditions and showed the types of potential systems that could be made available to the ATC community.

Many experts will agree that the current ATC system is ready for a change. The types of technologies that were developed under these NASA and FAA funded projects have the potential

to act as stepping-stones to the future of ATC technology.

Presented in this paper were results of several years of development and some possible ideas for improvement upon the presented technologies. The possibility of a fully automated ATC system can be argued to great extents. It is not likely that the world will see a fully automated system anytime soon, if ever. However, it is very possible to develop a system that requires less effort from the humans running the system, while increasing safety for the operators and travelers.

The systems presented show great potential and will hopefully answer questions about the possibility of a more automated system and maybe raise questions about new and exciting technologies.

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